Universality of the IMF

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Annual Reviews of
Astronomy & Astrophysics, 2010 + updates

Do observations provide unambiguous evidence for systematic IMF variations?

No.

(but I haven't given up hope.)

Yet.

Where might we find IMF variations?

Environments:
- Extended Solar Neighborhood/Galactic Disk
- 'normal' young clusters (Taurus->ONC)
- open clusters
- super star clusters
- Galactic Center
- Globular Clusters
- External Galaxies (e.g., van Dokkum & Conroy 2010, 2011)
- high-z universe
- Pop III

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- External Galaxies (e.g., van Dokkum & Conroy 2010, 2011)
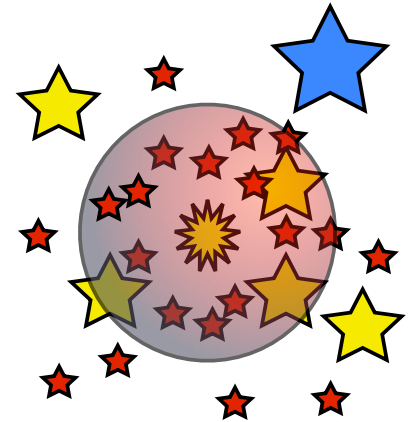- high-z universe
- Pop III

These environments span:
-- Factor of 100 in [Fe/H]
-- Factor of 1000 in resultant stellar density (10 -- 10^4 stars / pc^{-3})

The <u>cleanest</u> sample for measuring the Field MF

Volume
Complete
(trig. parallax)

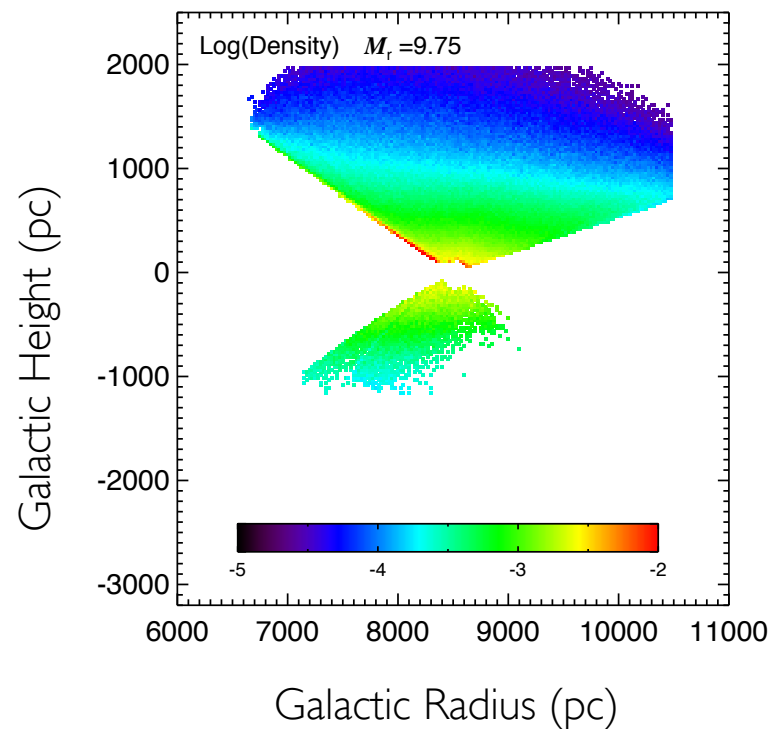* 25pc for solar-type stars: (454 stars; Raghavan et al. 2010)

* 8->10 pc for M stars: (140 stars; Reid & Gizis 1997; 369 stars; Henry et al. 2006)

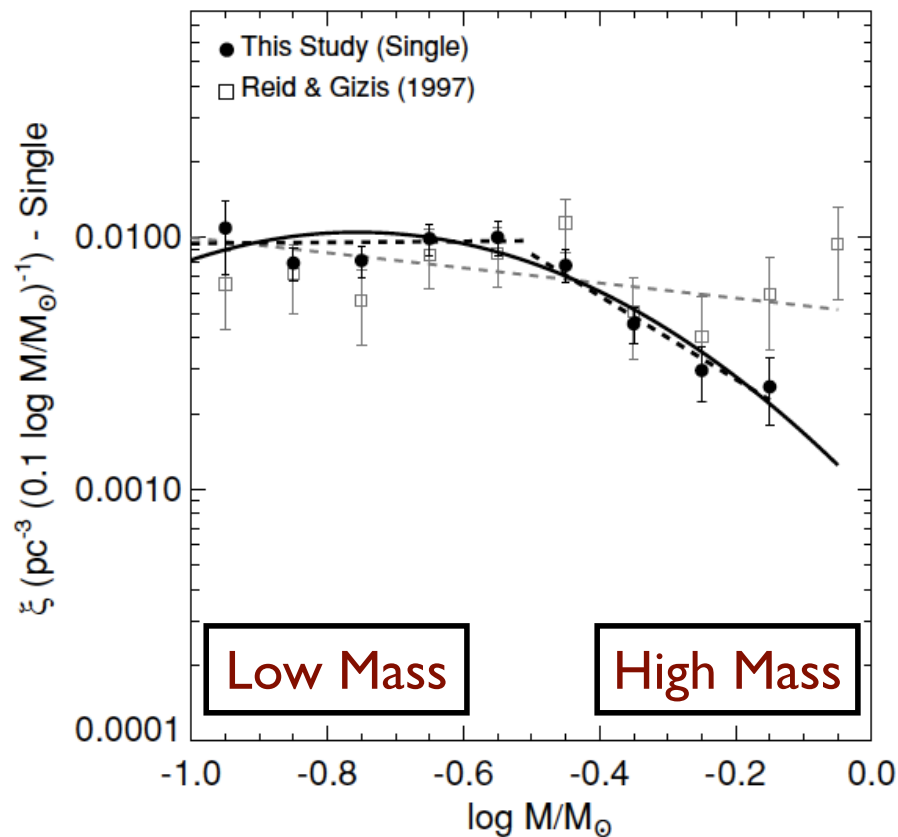# The <u>largest</u> sample for measuring the Field MF

Magnitude Limited
(phot. parallax; system MF)

* HST: 1400 M stars to I ~ 24 (Zheng et al. 2001)

* SDSS: 30K to J=16 (Covey et al. 2008); 15M to r ~ 22 (Bochanski et al. 2010)

A consistent sub-solar MF throughout the Galactic disk

Local MF statistically representative of MF to a few scale heights out of the Galactic disk:

$$\Gamma = 0.2$$

or

$$M_c = 0.25$$
$$\text{sigma} = 0.5 \text{ log-normal}$$
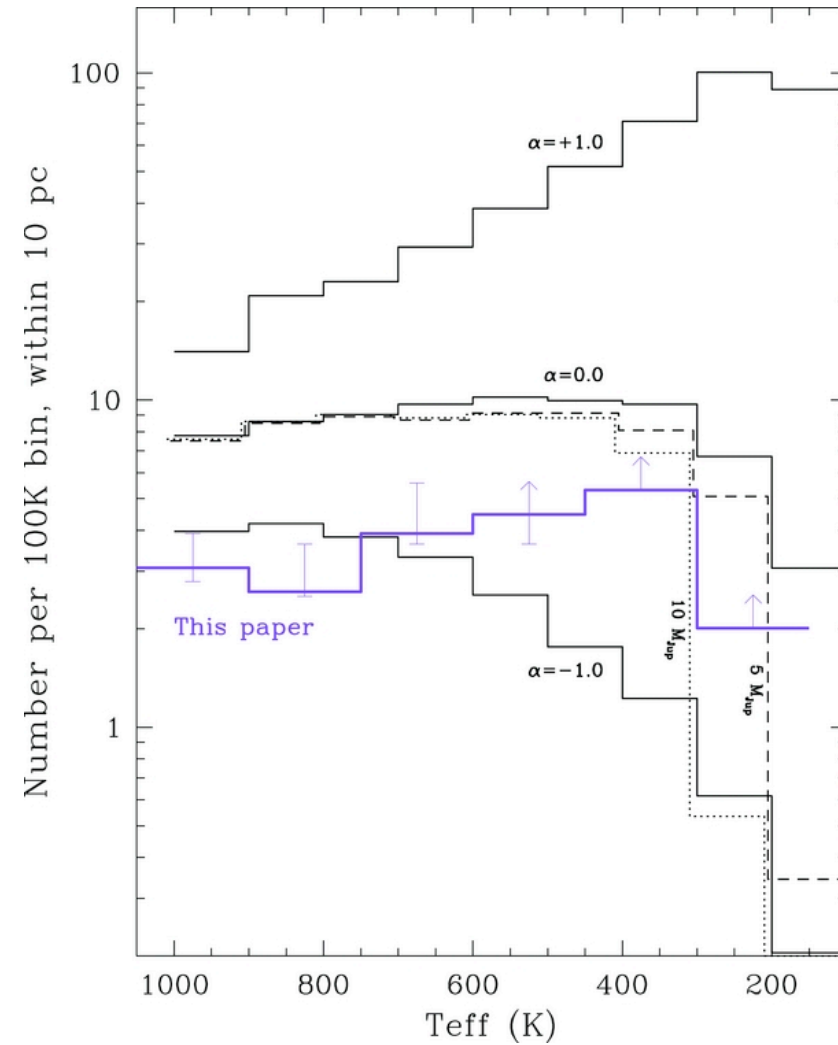
$$(0.1 < M < 1.0)$$

Low Mass **High Mass**

Covey et al. 2008; Bochanski et al. 2010

The sub-stellar MF in the Solar Neighborhood: a work in progress

- Large sample of BD T_{eff}s (e.g., Allen et al. 2005, Cruz et al. 2007, Metchev et al 2008; Burningham 2010, Lodieu et al. 2012, Kirkpatrick et al. 2012)
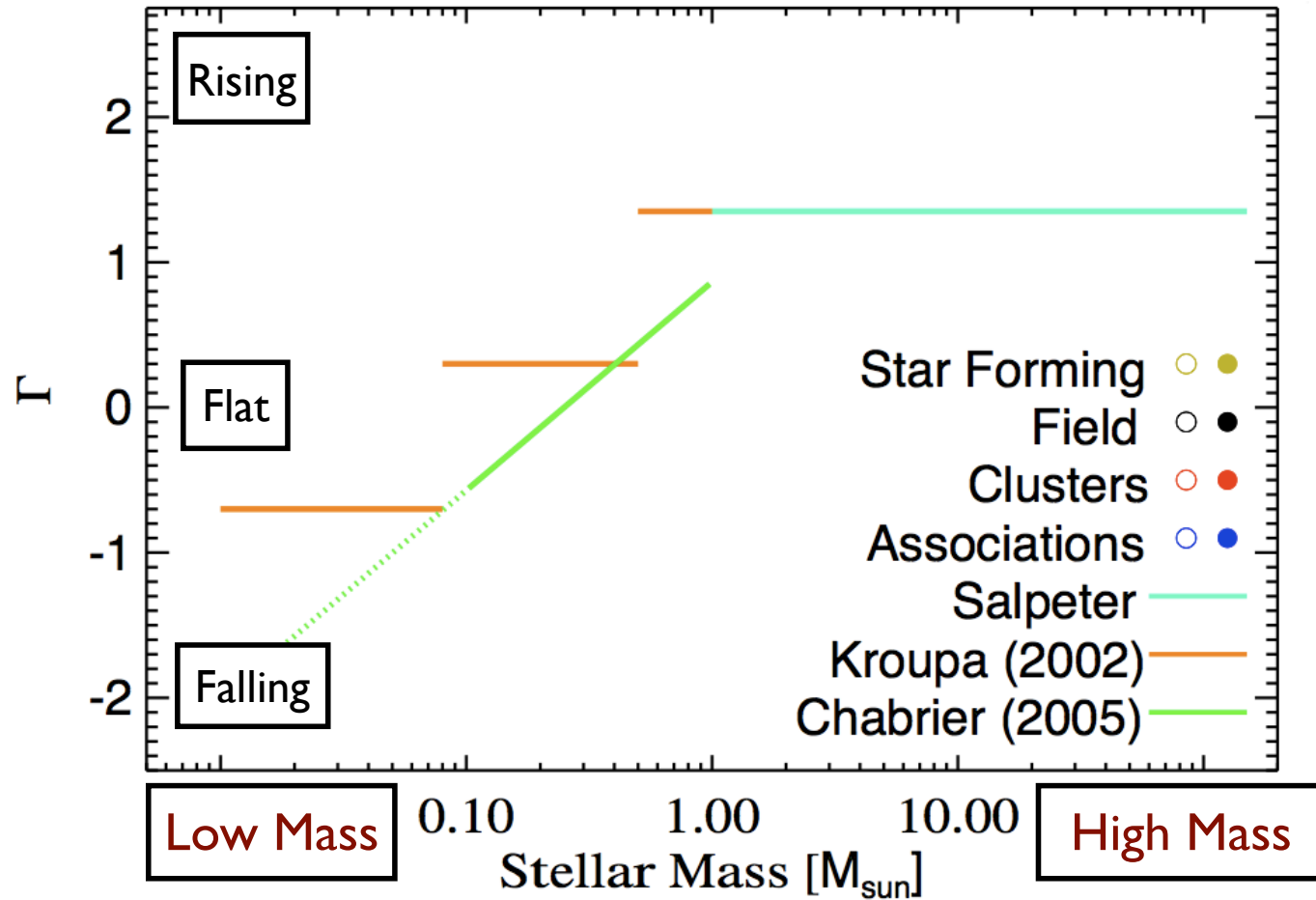
- $T_{eff} \neq$ Mass; BDMF must be inferred from models including BD evolution, MW SFH, etc. (e.g., Burgasser et al. 2004, Deacon & Hambly 2006, Pinfield et al. 2008)

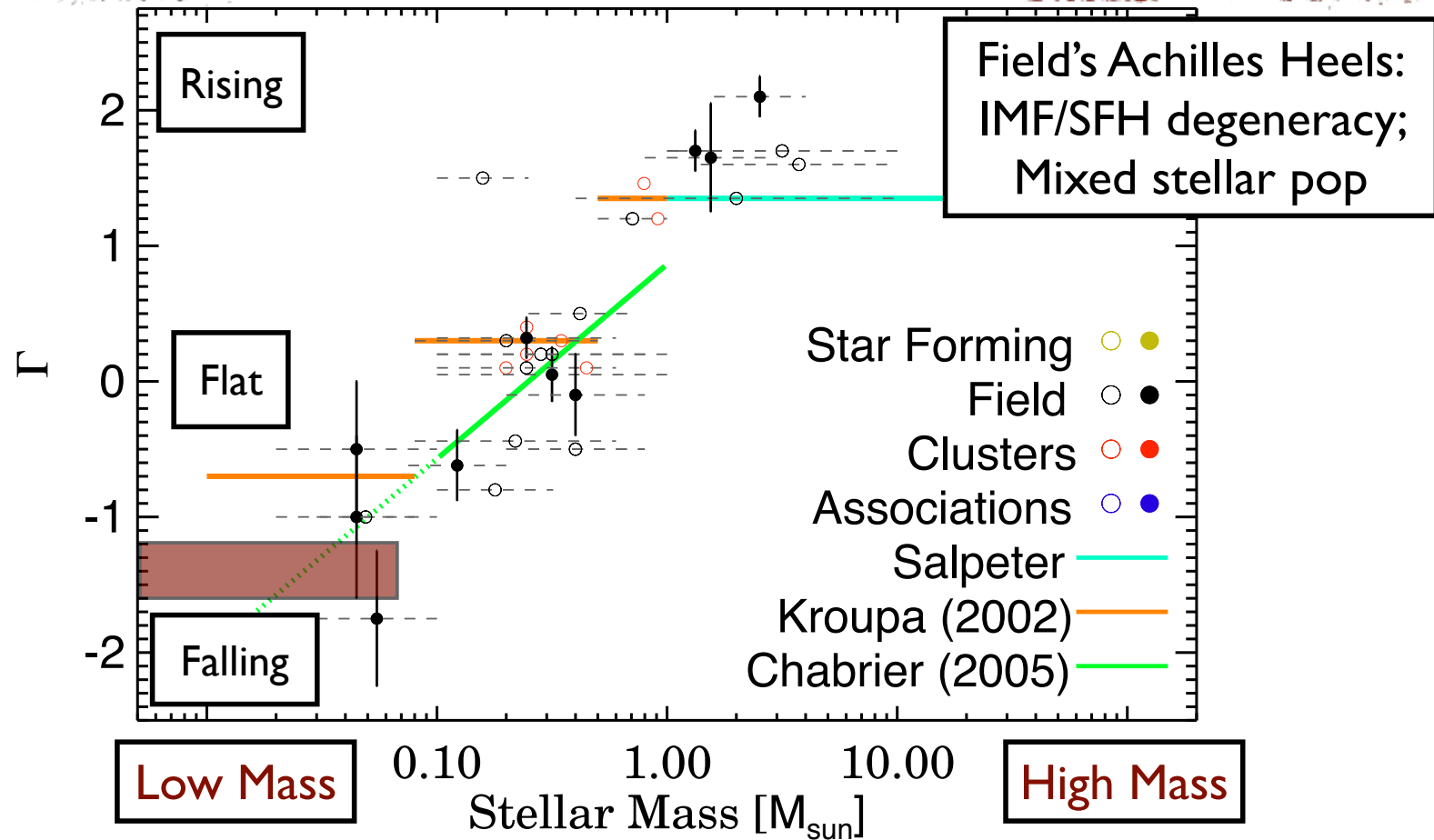- Results have large uncertainties but suggest $\Gamma <\sim$ -1.5

Kirkpatrick et al. 2012

Summarizing Field MFs

- Rising
- Flat
- Falling

Low Mass   High Mass

Star Forming ○ ●
Field ○ ●
Clusters ○ ●
Associations ○ ●
Salpeter
Kroupa (2002)
Chabrier (2005)

Stellar Mass [M$_{sun}$]

Summarizing Field MFs

Field's Achilles Heels:
IMF/SFH degeneracy;
Mixed stellar pop

Rising

Flat

Falling

Γ

Low Mass

High Mass

Stellar Mass [M_{sun}]

Star Forming
Field
Clusters
Associations
Salpeter
Kroupa (2002)
Chabrier (2005)

See: Rana & Basu 1992; Maciel & Rocha-Pinto 1998; Reid, Gizis & Hawley 2002; Schroder & Pagel 2003; Martini & Osmer 1998; Gould et al. 1997; Reid & Gizis 1997; Zheng et al. 2001; Reyle & Robin 2001; Schultheis et al. 2006; Robin et al. 2007; Vallinari et al. 2006; Deacon, Nelemans & Hambly 2008; Covey et al. 2008; Bochanski et al. 2010; Reid et al. 1999; Allen et al. 2005; Metchev et al. 2008; Pinfield et al. 2008; Burningham et al. 2010; Reyle et al. 2010
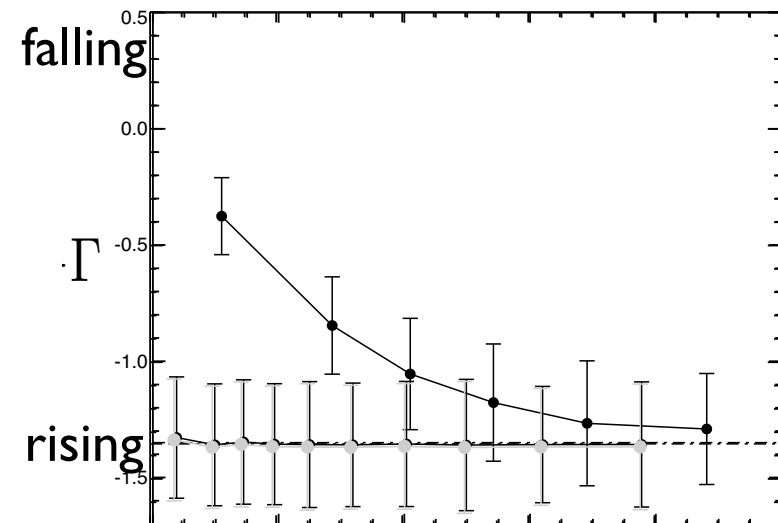
Clusters: laboratories for IMF variations w/ environment

NGC 6341

[Fe/H] =-2.16

NGC 5927

[Fe/H] =-0.7
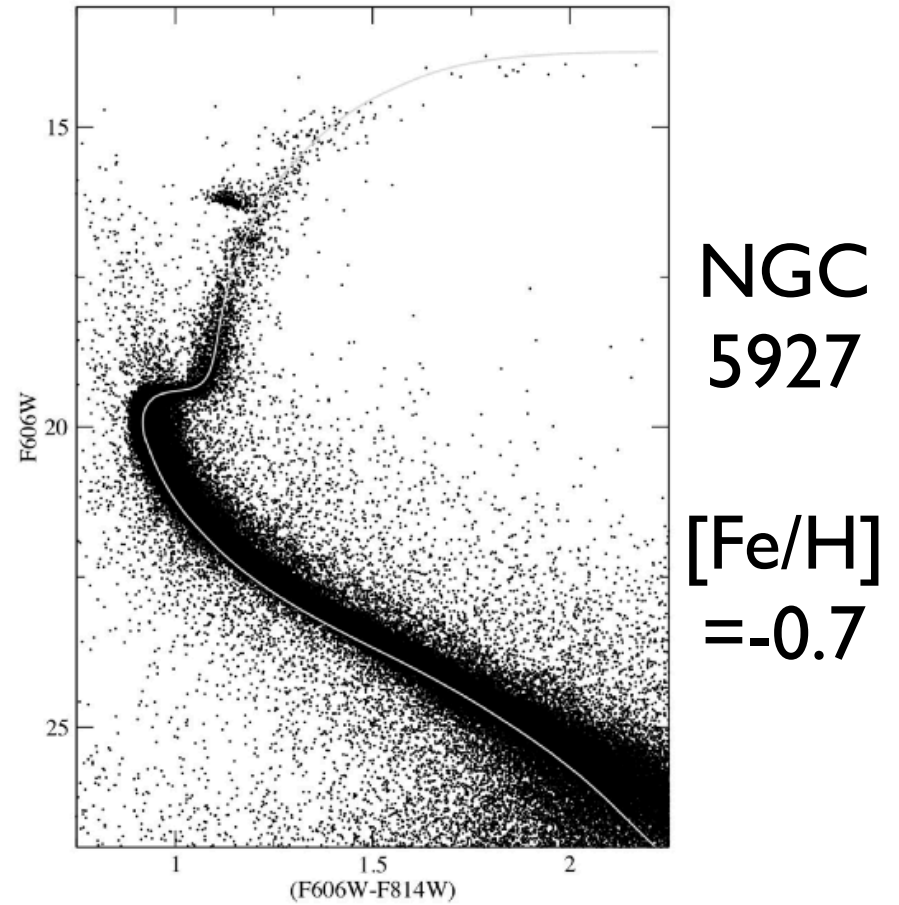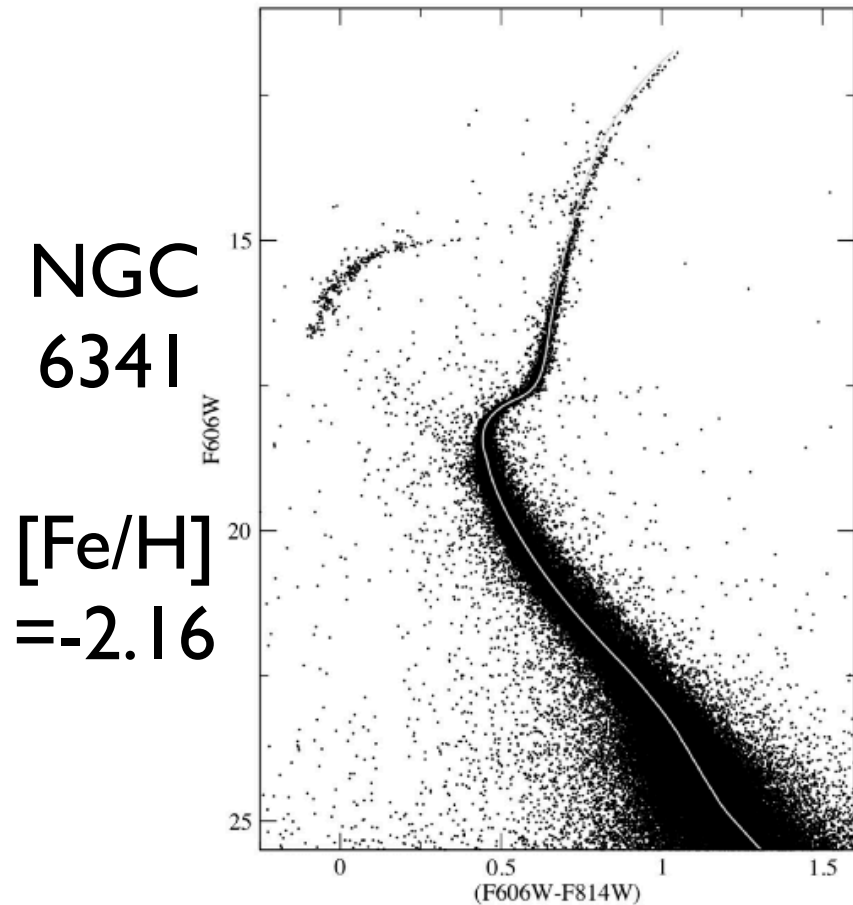
Paust et al. 2010

Mass segregation: a challenge for MF measurements in dense clusters
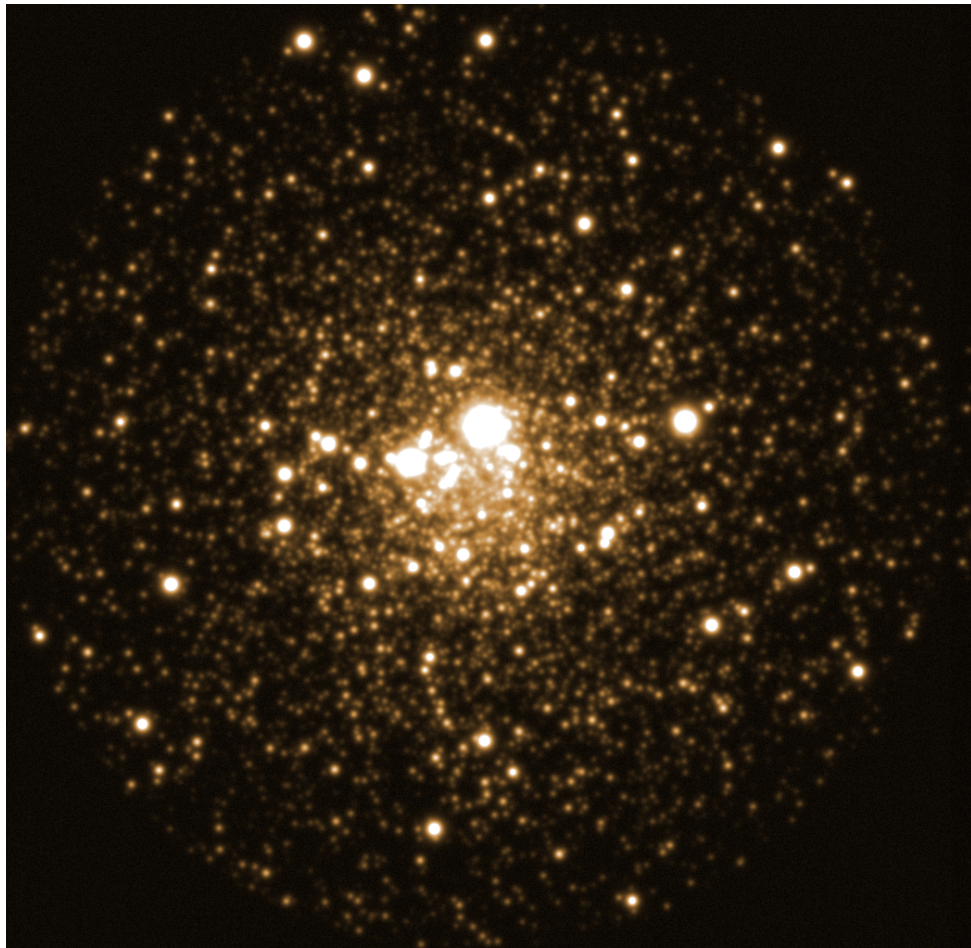
- Mass segregation: intrinsic or apparent?

falling

$\cdot\Gamma$
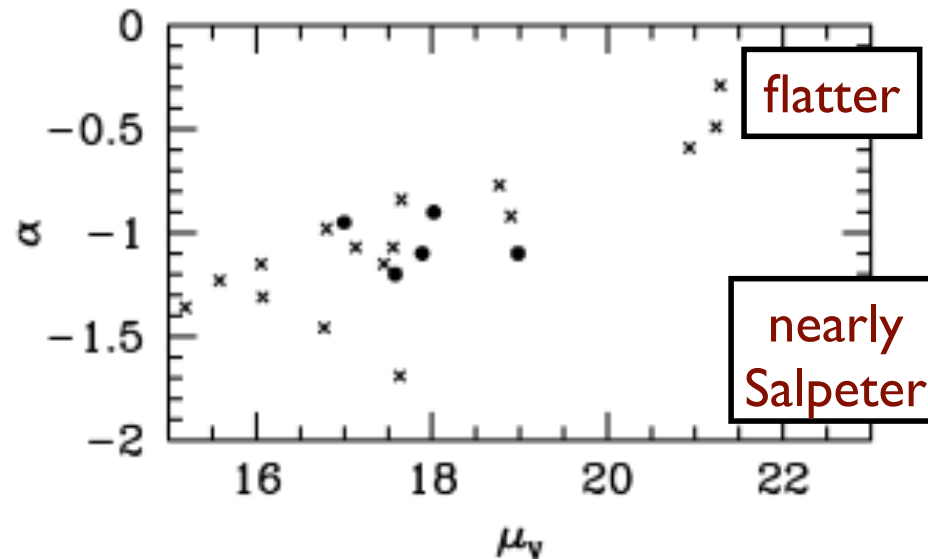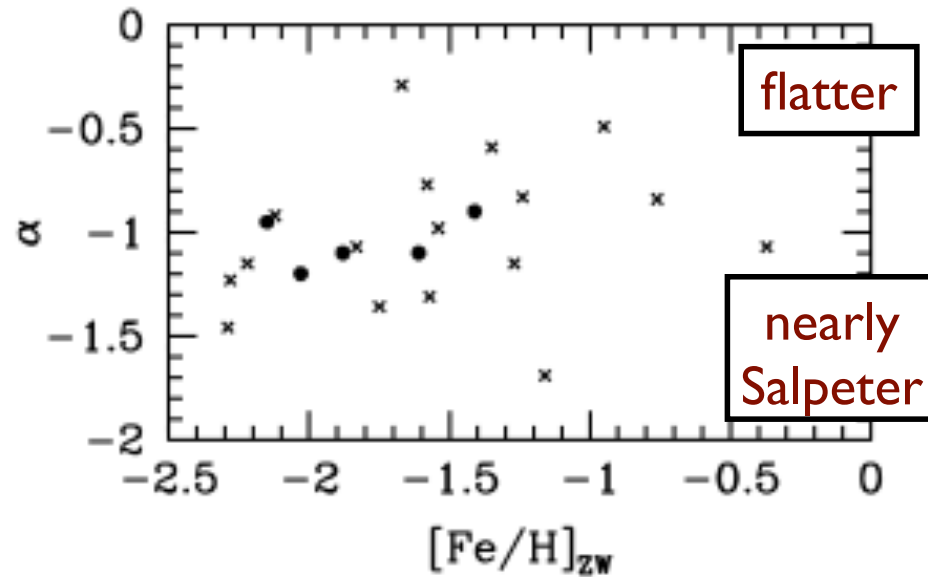
rising

cluster radius

Ascenso et al. 2009

MF variations in globular clusters, but not <u>IMF</u> variations: massive clusters better able to hold onto their low mass members

flatter

nearly Salpeter

flatter

nearly Salpeter

Paust et al. 2010

Young cluster (stellar) MFs: a fair consensus, with notable exceptions

- Most MFs consistent w/ field, within errors, down to ~0.2 M_o:
  - ONC: Muench et al. 2002, Da Rio et al. 2010
  - Sigma Ori: Caballero 2009
  - Upper Sco: Lodieu et al. 2011
  - Rho Oph: Erickson et al. 2011
  - IC348: Luhman et al. 2003
  - Cha I: Luhman 2007

- Notably anomalous young cluster in stellar mass regime is Taurus (e.g., Luhman et al. 2009)

- Also evidence for mass segregation at youngest ages (e.g., Kirk & Myers 2011, 2012; Kryukova et al. 2012)


Low Mass   High Mass
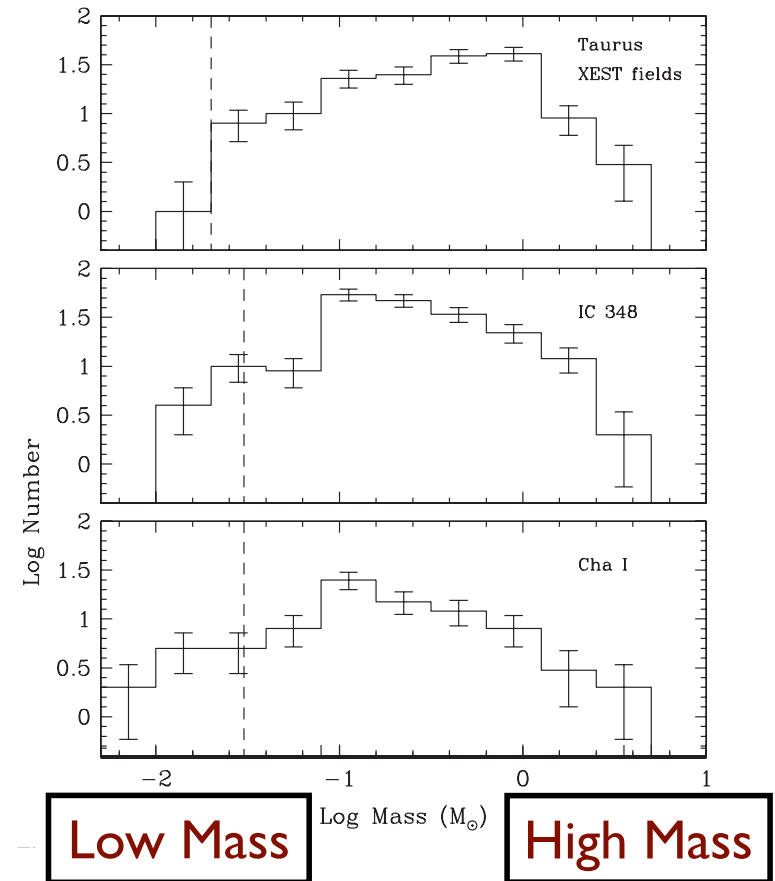
Luhman et al. 2009

The sub-stellar MF: excesses in young clusters?

- Many young clusters return MFs with Γ ~ -0.4, in excess of field BDMF (e.g., Upper Sco: Slesnick et al. 2008, Lodieu et al. 2011; Sigma Ori: Caballero et al. 2007; ONC: Muench 2002)

- Deficits of BDs also reported, however: Rho Oph (Erickson et al. 2011; but see also Geers et al. 2011)

- Also lack of additional members in deep survey of NGC 1333 -- bottom of MF? (Scholz et al. 2009)
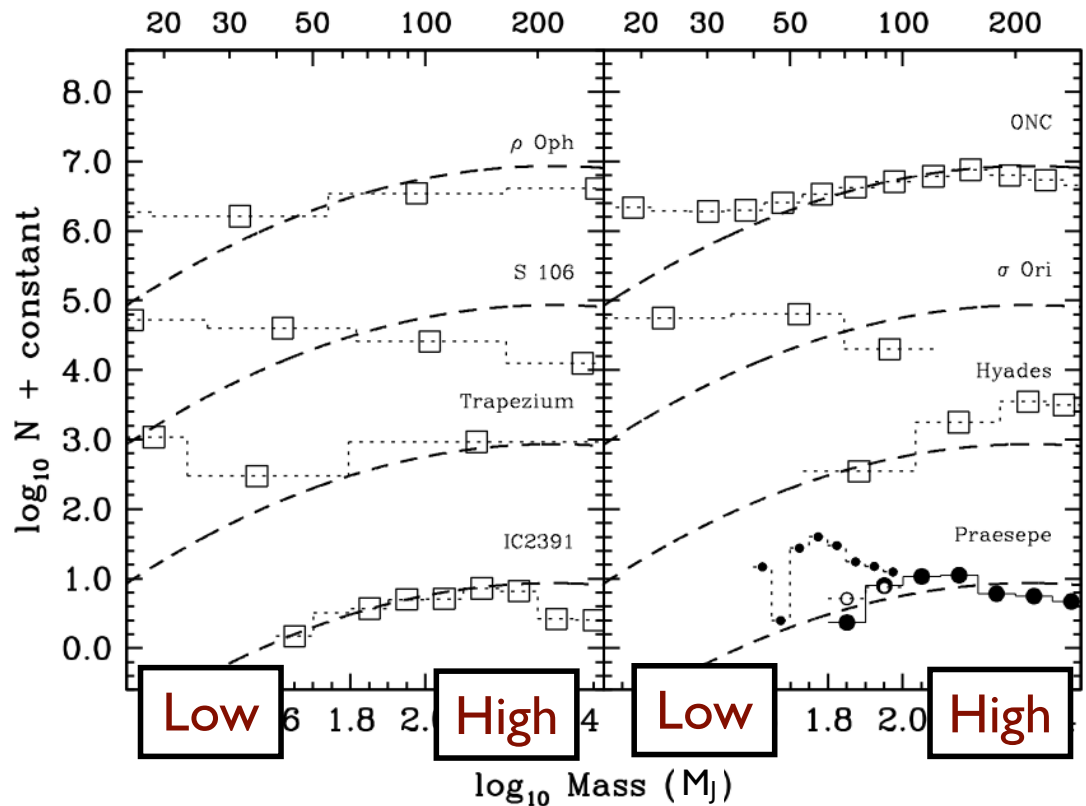
Wang et al. 2010

Summarizing Cluster MFs
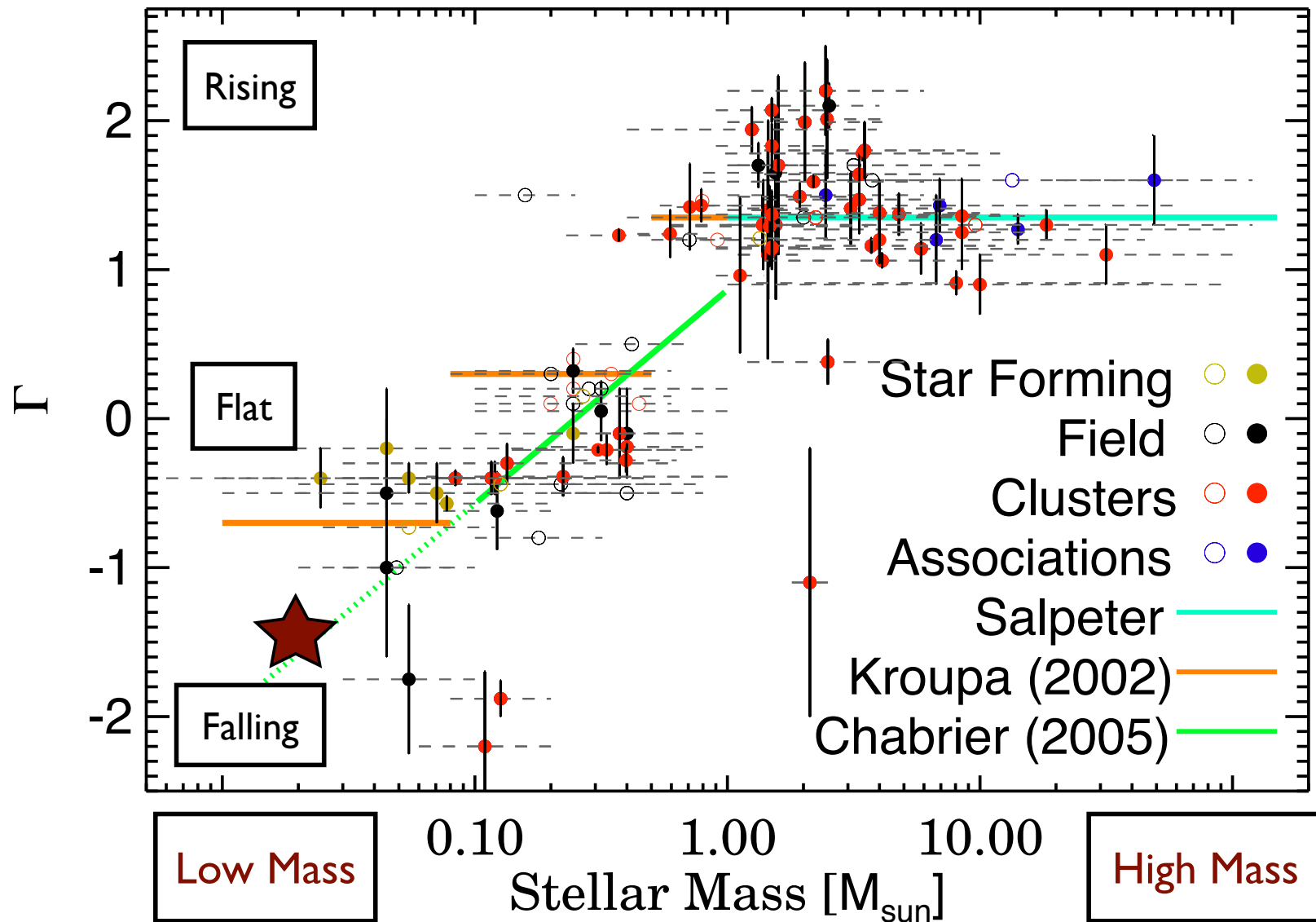
The take home messages (I)

- Kroupa/Chabrier MF measured in vast majority of field/cluster environments (where stars can be resolved).

  - Slight bias towards super Salpeter slopes near 1 M_o: SFH corrections?

  - Excess of BDs seen in MFs of youngest clusters vs. the field: problems with BD evol. models? SFH of MW? actual MF differences?

  - Specific clusters deserve more attention (Taurus, Hyades/Praesepe), but no systematic variations seen.

  - Evidence for mass segregation at youngest ages: intrinsic or dynamical?

The take home messages (II)

- Next generation of studies require improved:

  - parallaxes (expansion of volume complete sample)

  - red sensitivity (sub-stellar MF; extinction in young clusters)

  - cluster kinematics (binary fraction vs. age; identify or rule out intrinsic mass segregation (i.e, spatial IMF variations within a single environment)

- APOGEE & Gaia + LSST can provide all this!

Kinematics of young clusters can test for primordial mass segregation (ie, spatial IMF variations)...


Furesz et al. 2008
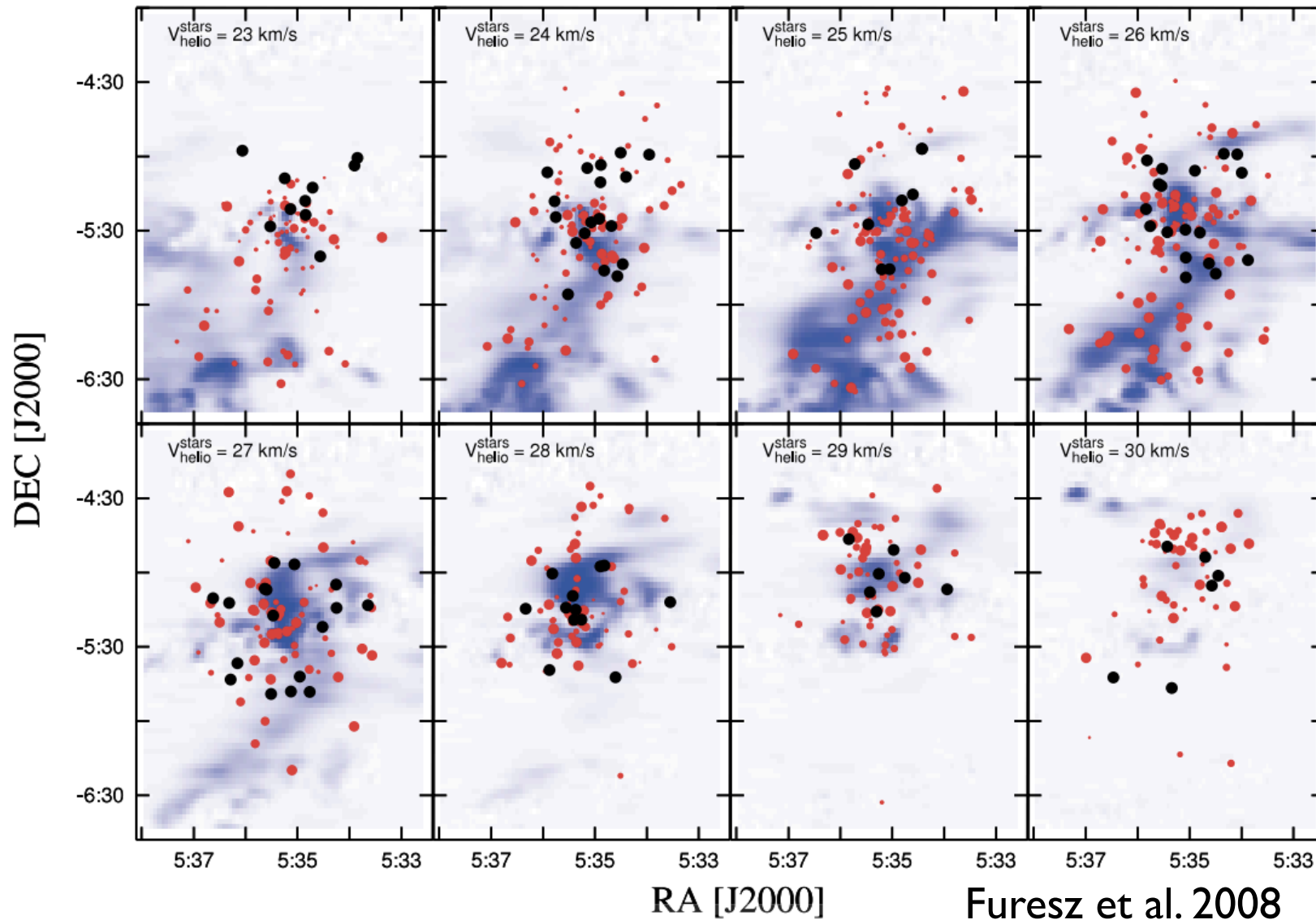
Kinematics of young clusters can test for primordial mass segregation (ie, spatial IMF variations)...

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  - ~0.5 km/s astrophysical limit for optical RV measurements (e.g., Mahmud et al. 2011);
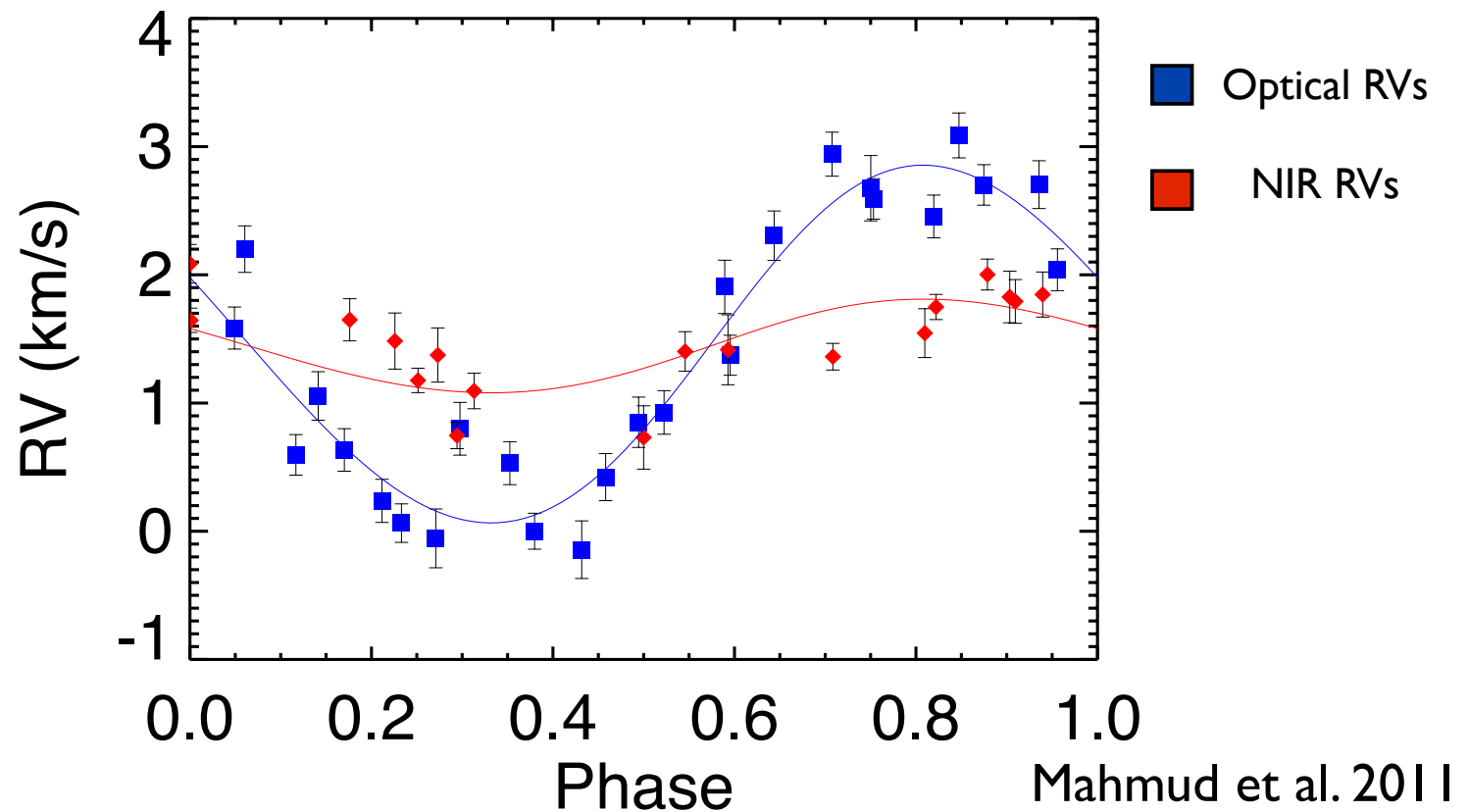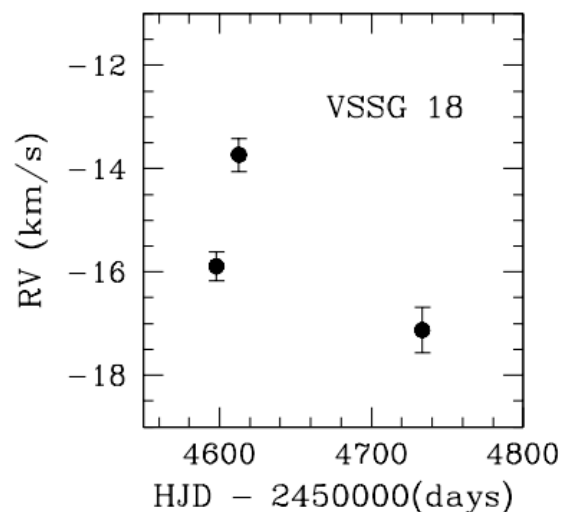

Mahmud et al. 2011

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- ...but current measurements strain against:

  - ~0.5 km/s astrophysical limit for optical RV measurements (e.g., Mahmud et al. 2011);

  - limited capacity for precise NIR measurements (e.g., Covey et al 2006; Viana Almeida et al. 2012).
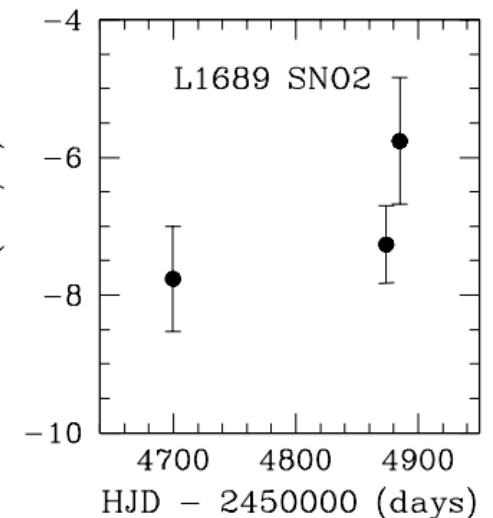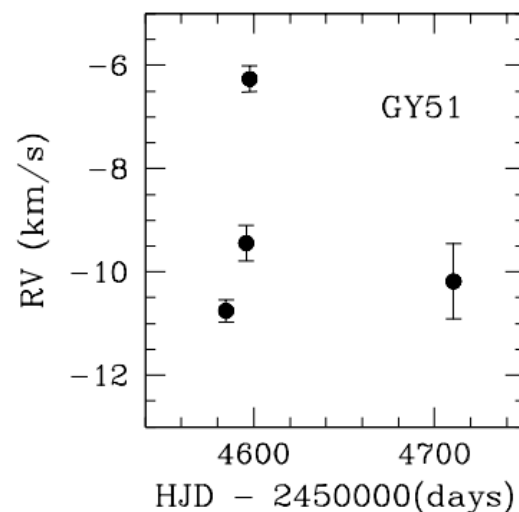

Viana Almeida et al. 2012

Area of Opportunity for APOGEE

- Enter APOGEE:

  - U. of VA-built high-res (R~20000) multi-fiber (n~230) H-band spectrograph for the SDSS 2.5m telescope (2.5 deg FOV).
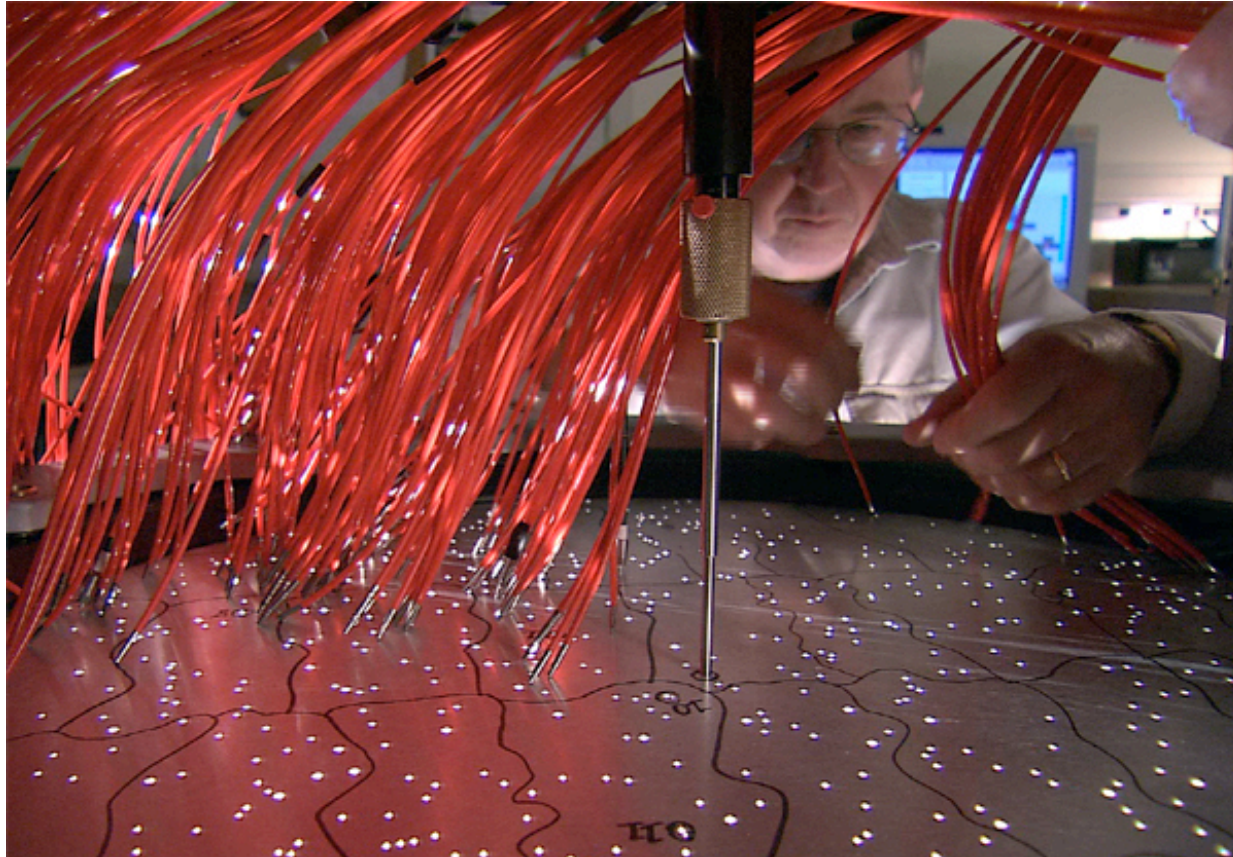
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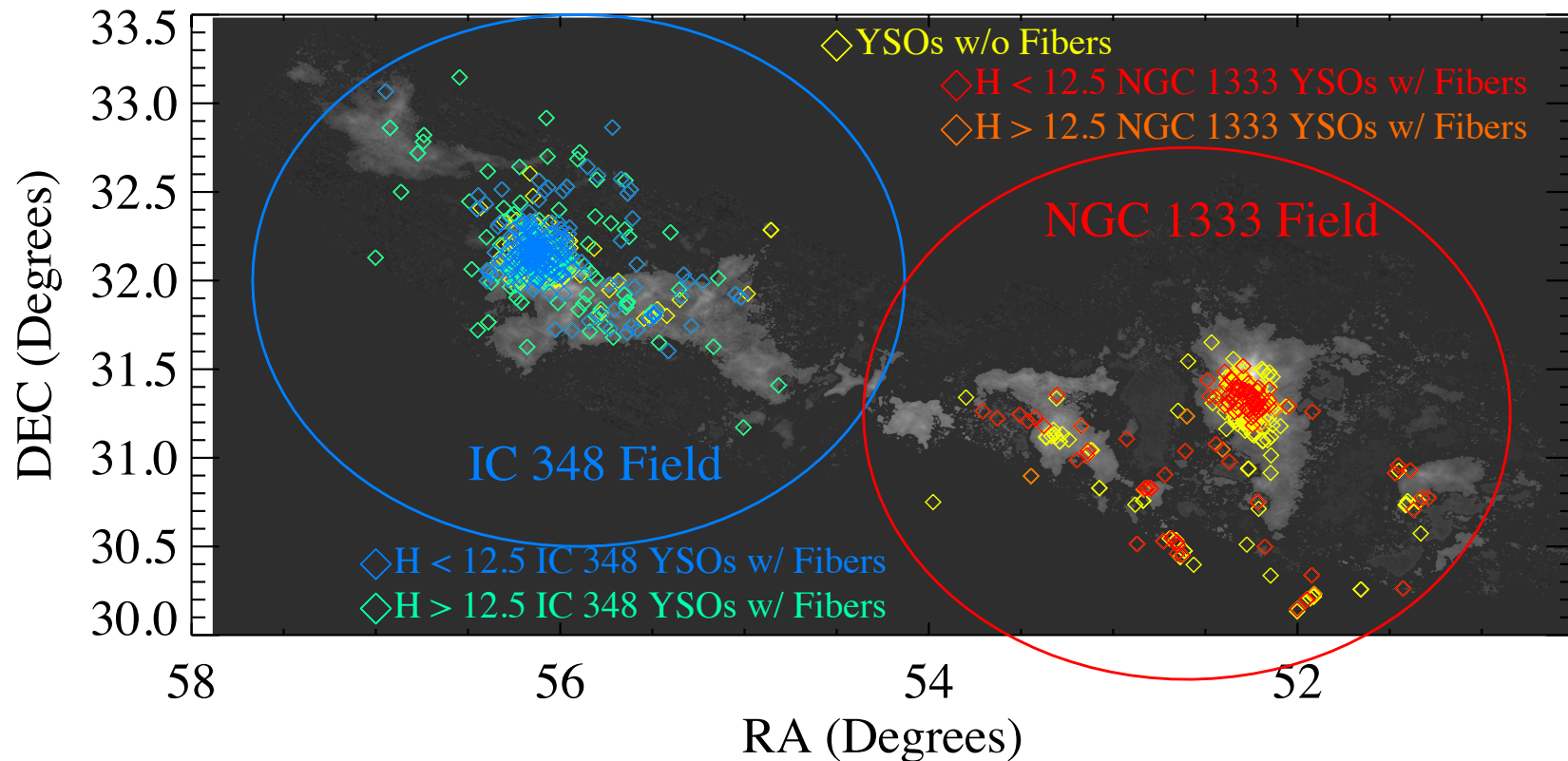 - ~50 m/s velocity precision serendipitously demonstrated (for field stars) via 8 epochs on HD 114762
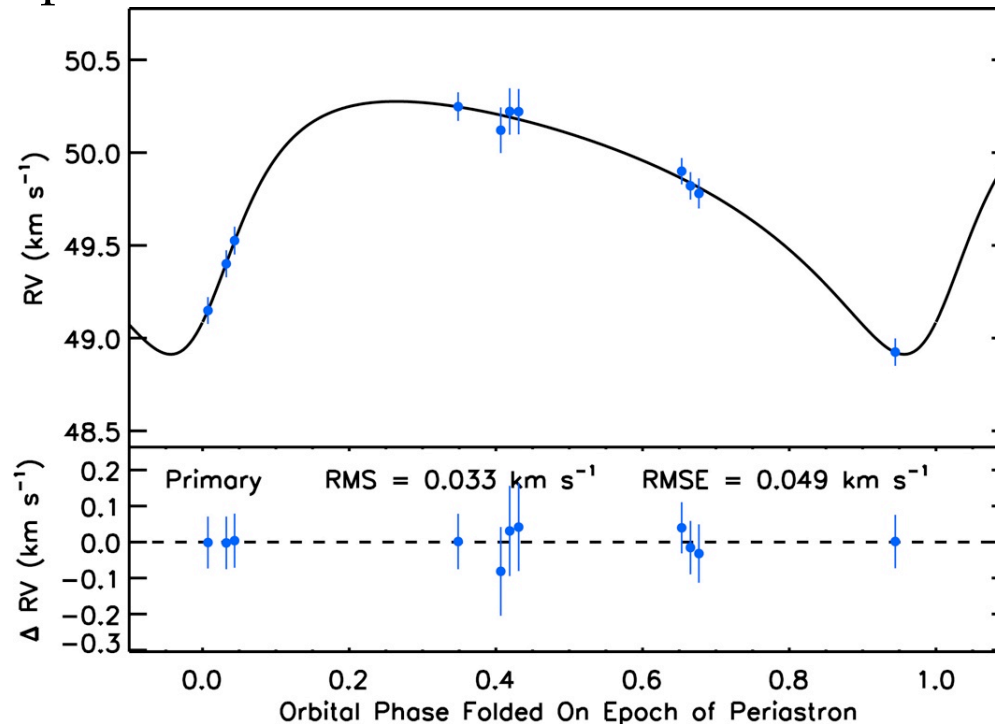
Proposed IN-SYNC Observations

- 1-6 epochs for 350 YSOs in IC 348 & 1-3 epochs for 120 YSOs in NGC 1333 over remainder of SDSS-III period (~Sept. 2014)

- Targeting maximizes completeness over coverage; split epochs for objects within 71" fiber collision radius

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